High Performance Computing (HPC) Enabled Computation of Demand Models at Scale to Predict the Energy Impacts of Emerging Mobility Solutions

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LBNL

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Project ID # eems042

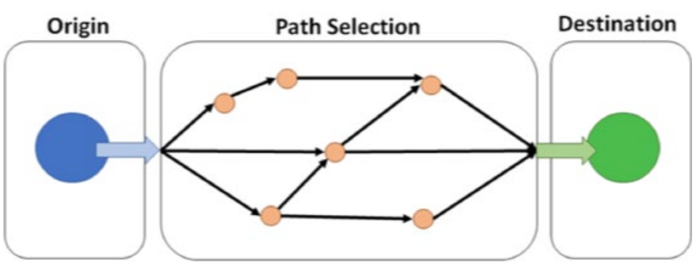
Overview

Timeline

- Project Start: April 2018
- Project End: April 2019
- 100% complete

Budget

- Total project funding
- $250K/ 1 year



Barriers

- Complexity of urban-scale integrated transportation networks are too large to model in reasonable compute time. With traffic assignment approach, routing accounts for 95% of compute.
- Traffic assignment has traditionally focused only on travel time, not energy use.
- The impact of active route control across connected vehicles is unknown, yet is a key part of current urban scale mobility dynamics.

Partners

- Connected Corridors, UCB
- CalTrans, DOT
- LA Metro

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Relevance

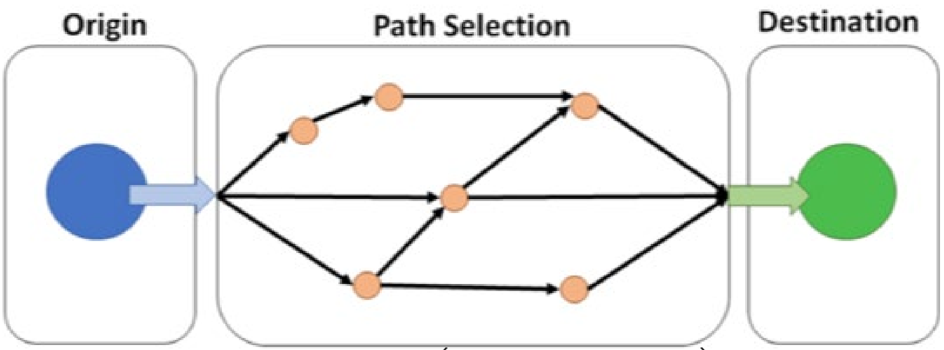
Urban-scale energy modeling of integrated transportation network behavior and associated impact of new vehicle technologies using traffic assignment methodologies

- Connected vehicles: How should they share information?
- Use of navigation apps: Best design of routing algorithms for energy and mobility
- Efficient response to network disturbances: What is the best mechanism for routing traffic efficiently in events and emergencies?

Use of high performance computing to address the compute load in the traffic assignment methodologies and model energy use in large scale networks

- Distribute computational load of routing algorithm across multiple nodes
- Provide an energy cost function to evaluate energy impacts

Approach: Contrast Travel Time to Fuel Use in TA

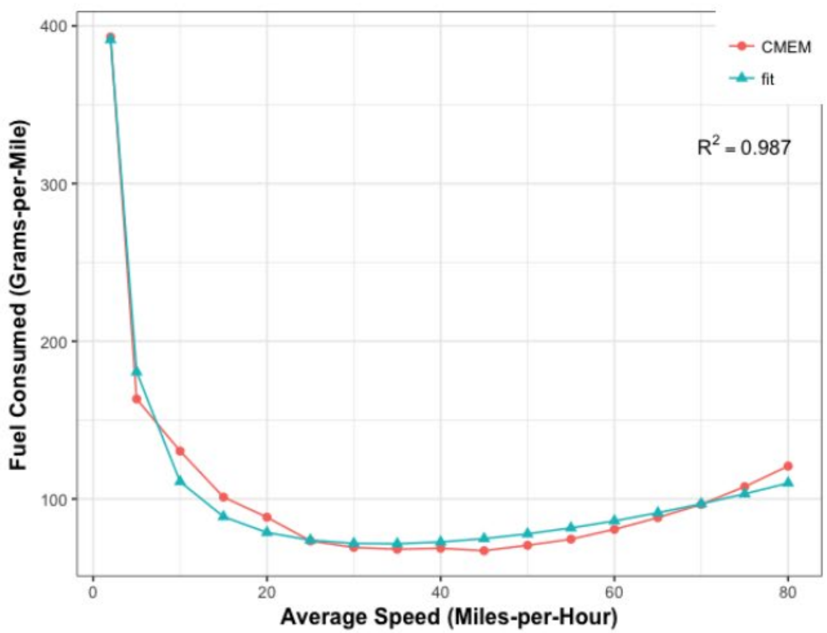


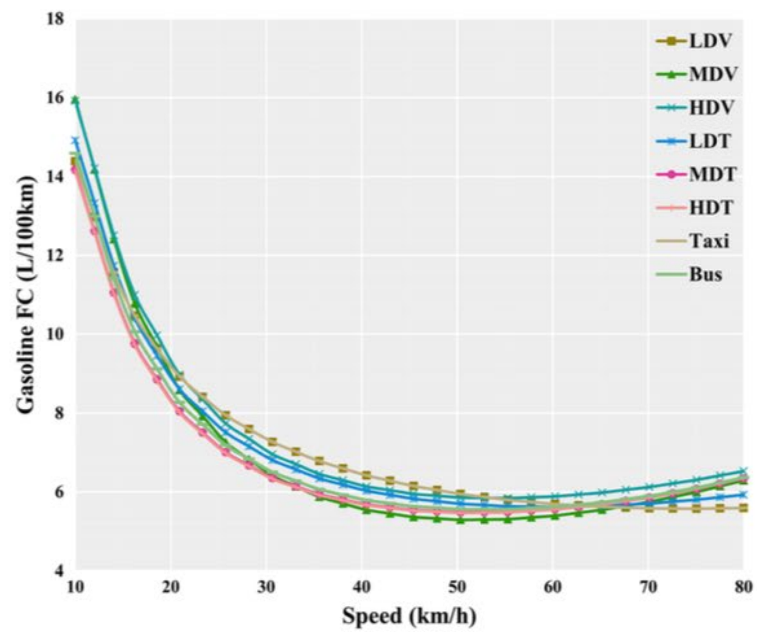
$$S_a\left(v_a\right) = t_a\left(1 + 0.15\left(\frac{v_a}{c_a}\right)^4\right)$$

An assignment h* is an equilibrium assignment if it satisfies

$$(h - h^*) \cdot F(h^*) \geq 0,$$

for all possible assignment h





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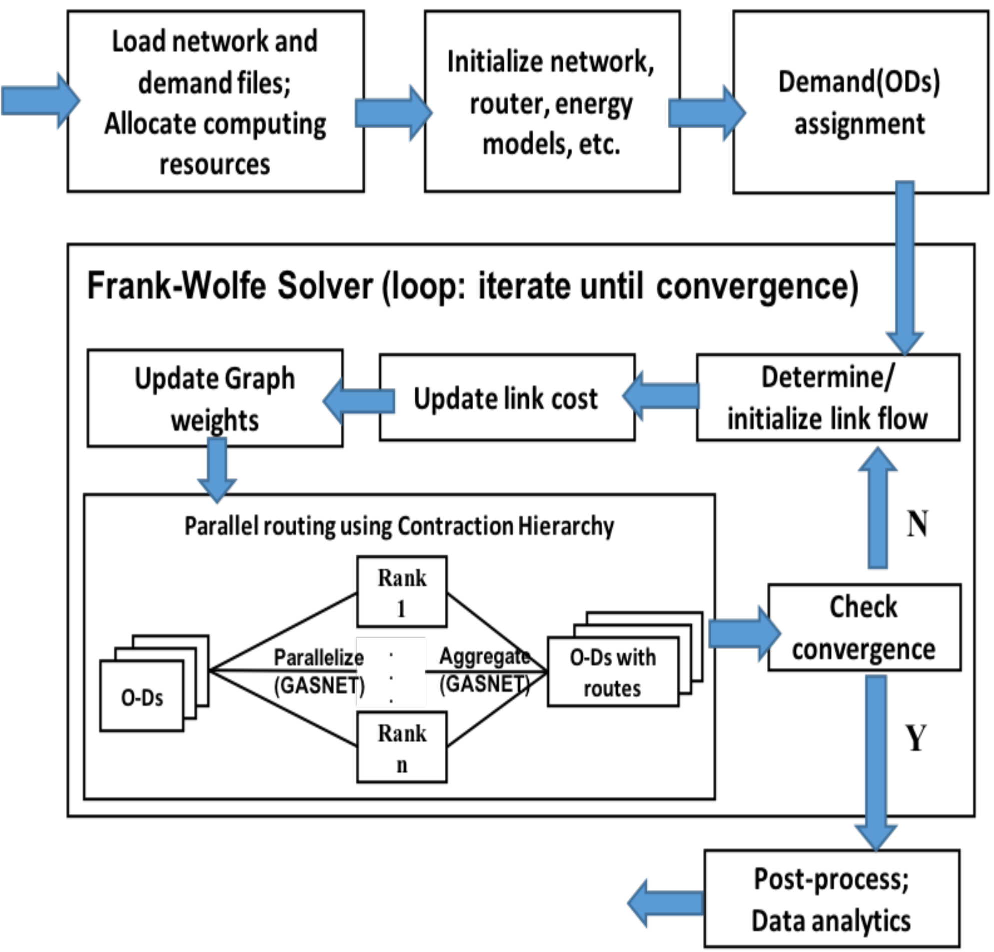
Approach: Parallelization of TA on HPC

ETAP Approach Overview (using Cori)



Mathematical Formulations (Abbrev.)

Objective:
$$\min_{Q,h} \sum_{a\in\mathcal{A}} \int_0^{Q_a} X_a(s)\,ds \tag{1}$$

s.t.

Wardrop conditions (2)

Network constraints (3)

$$t(Q_a) = t_a^0 \cdot \left(1 + \alpha \cdot \left(\frac{Q_a}{c_a}\right)^{\beta}\right) \tag{4}$$

$$\mathrm{EF}_{\mathrm{fuel}}(v_a) = A + \frac{B}{v_a} + C \cdot v_a^2 \tag{5}$$

$$F(Q_a) = Q_a \cdot L_a \cdot \left(A + \frac{C \cdot v_a^2}{\left(\alpha \cdot \left(\frac{Q_a}{c_a}\right)^{\beta} + 1\right)^2} + \frac{B \cdot \left(\alpha \cdot \left(\frac{Q_a}{c_a}\right)^{\beta} + 1\right)}{v_a} \right) \tag{6}$$

$$X_a = t(Q_a),\ \text{Time-based user equilibrium} \tag{7}$$

$$X_a = F(Q_a),\ \text{Energy/fuel-based user equilibrium} \tag{8}$$

$$X_a = t(Q_a) + \frac{dt(Q_a)}{dQ_a} \cdot Q_a,\ \text{Time-based system optimal} \tag{9}$$

$$X_a = F(Q_a) + \frac{dF(Q_a)}{dQ_a} \cdot Q_a,\ \text{Energy/fuel-based system optimal} \tag{10}$$

Q_a:	Flow on link a;	v_a:	Free flow speed of link a;
c_a:	Capacity of link a;	α:	0.15;
L_a:	Length of link a;	β:	4;
t_a^0:	Free flow travel time of link a;	X_a:	Cost function of link a;
$\mathcal{A}$:	All links in the network;	A, B, C:	Curve fitting coefficients;

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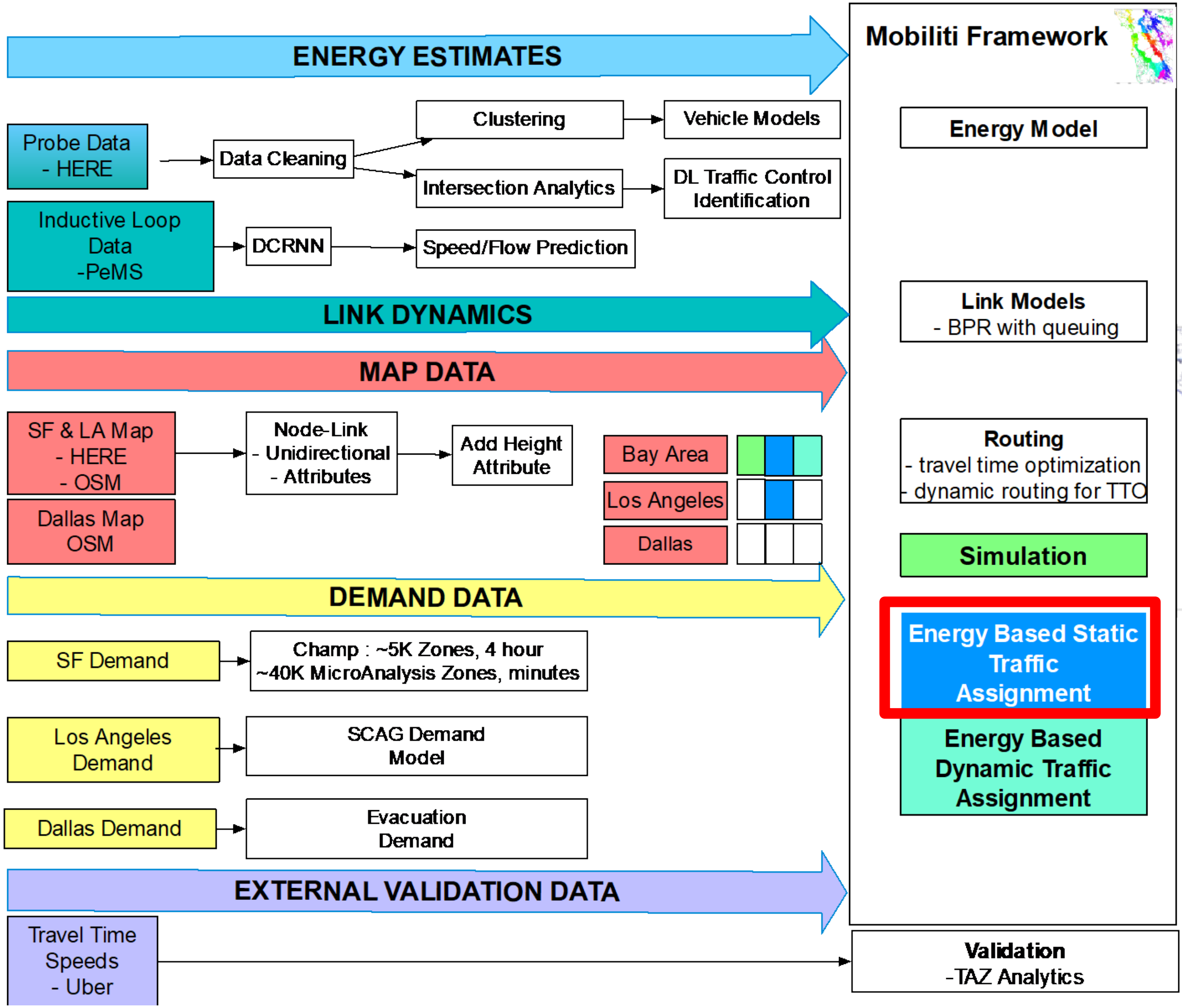
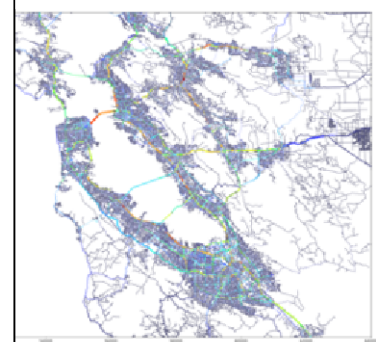
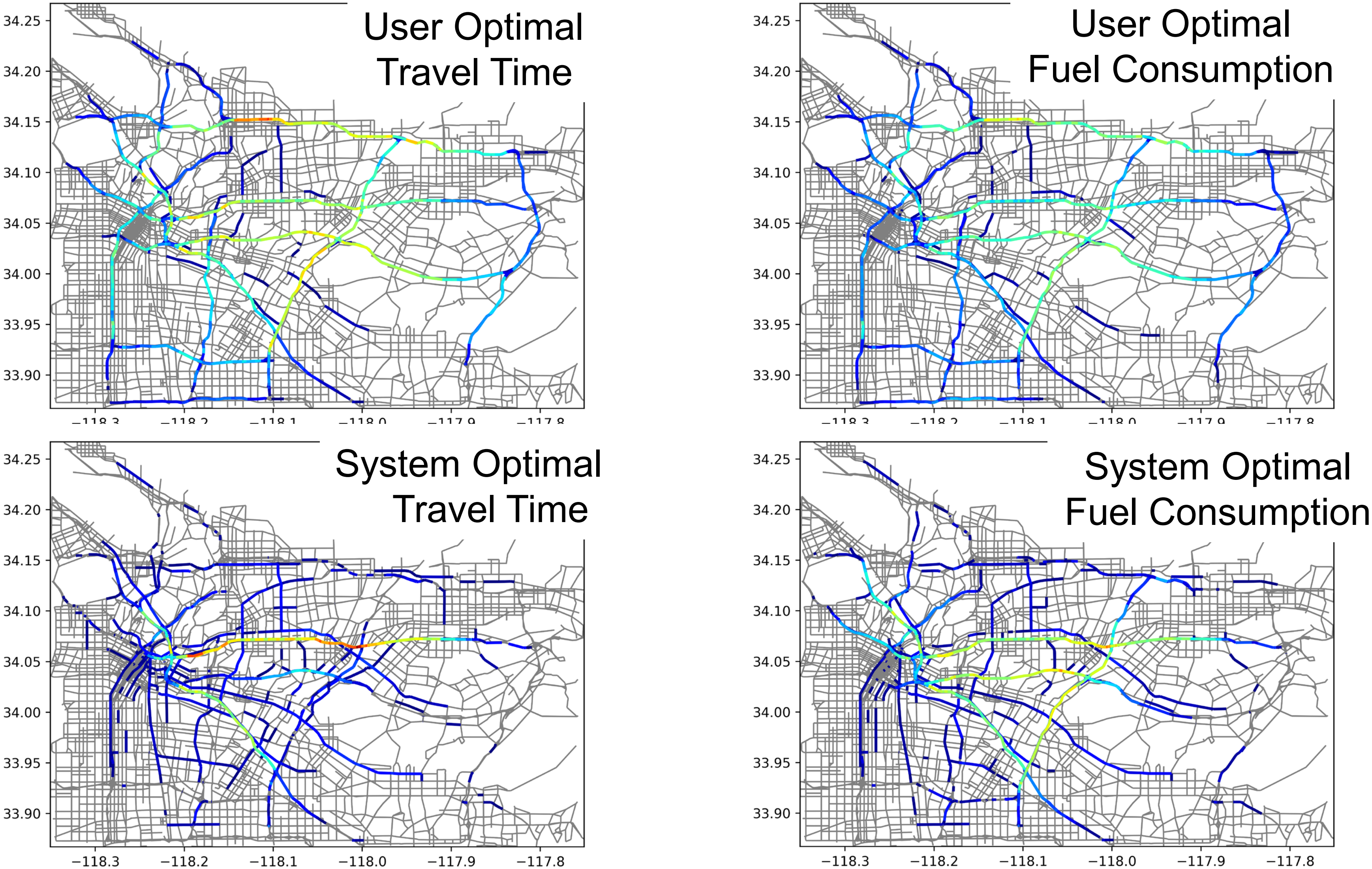
Framework Provided by Sister Project Mobiliti





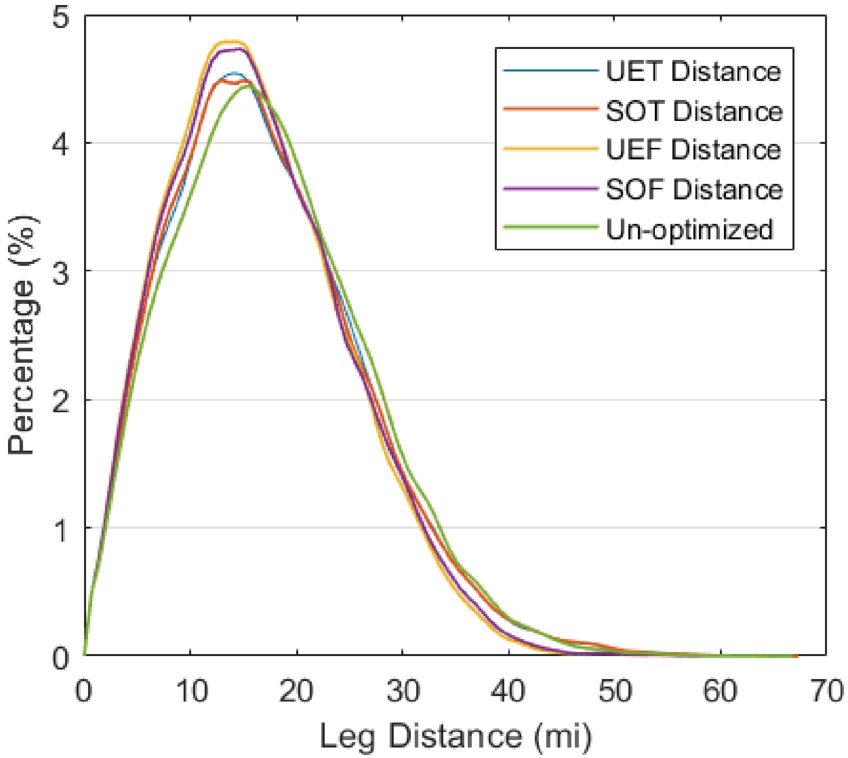
Metropolitan Scale Traffic Dynamics

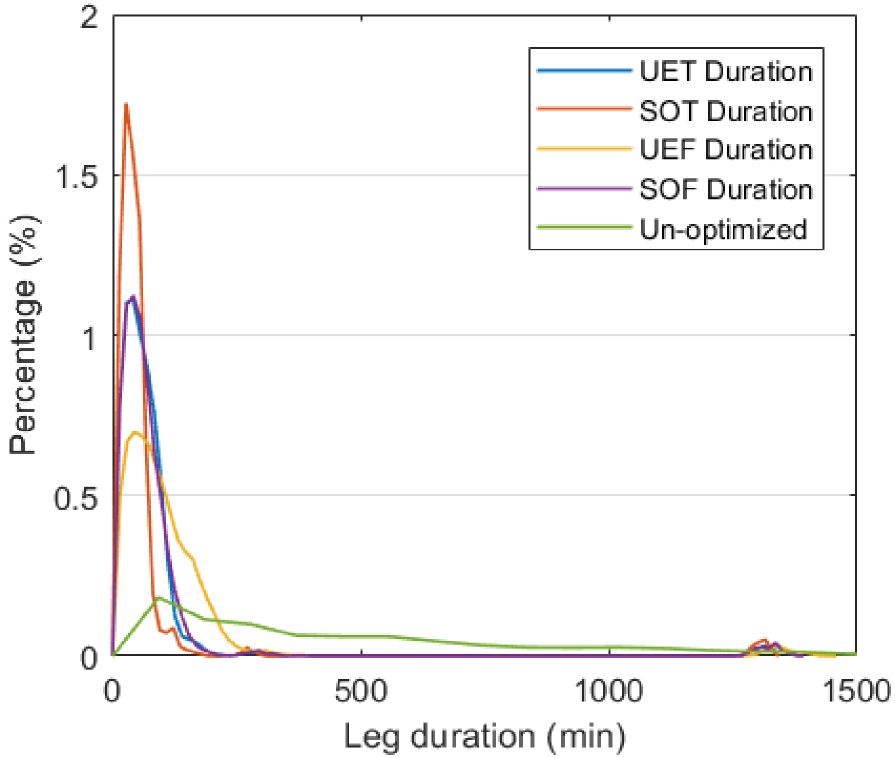
Major Flow Variation Across Optimization Algorithms Los Angeles Connected Corridor Region



Flow in (Vehicles/Second)

LA Network: Distance and Time Impact





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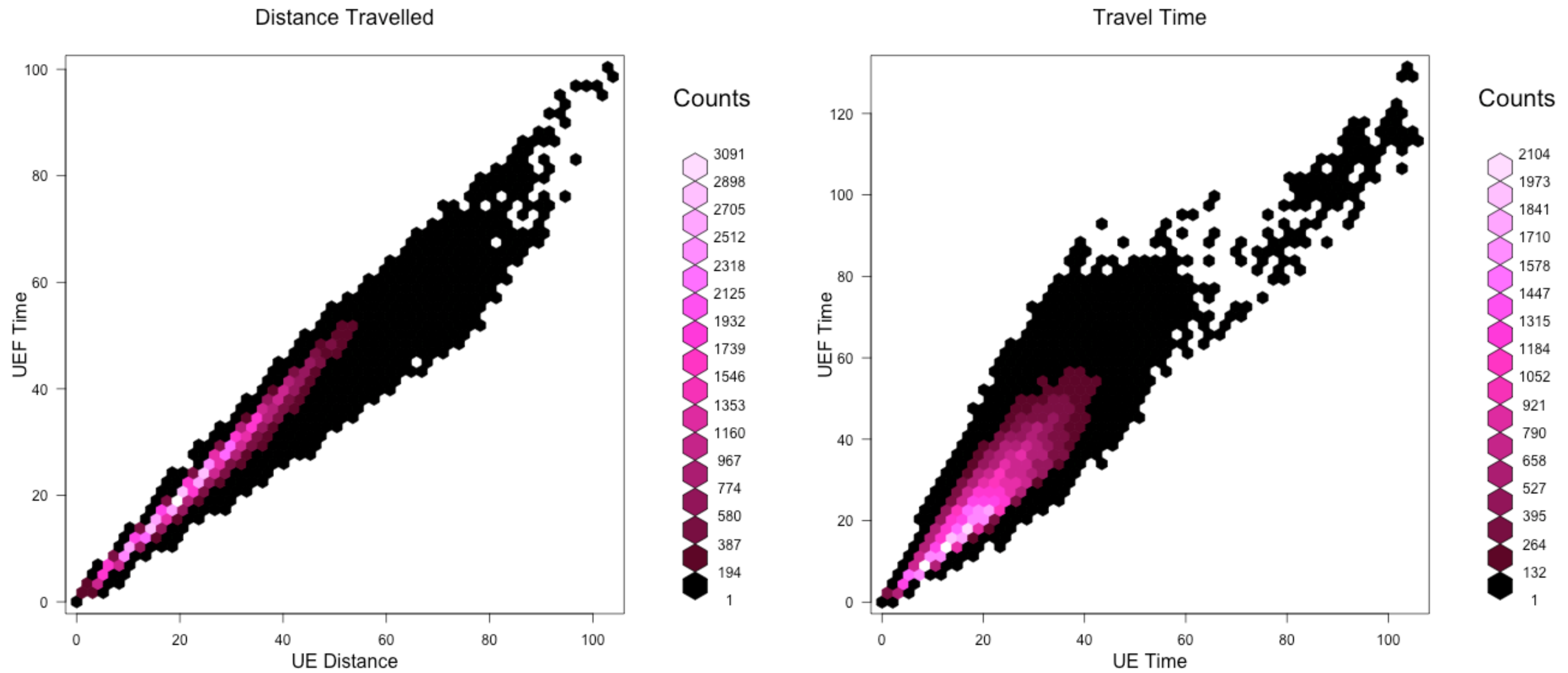
Impact of User Fuel Optimization



Normalized to User Equilibrium Travel Time

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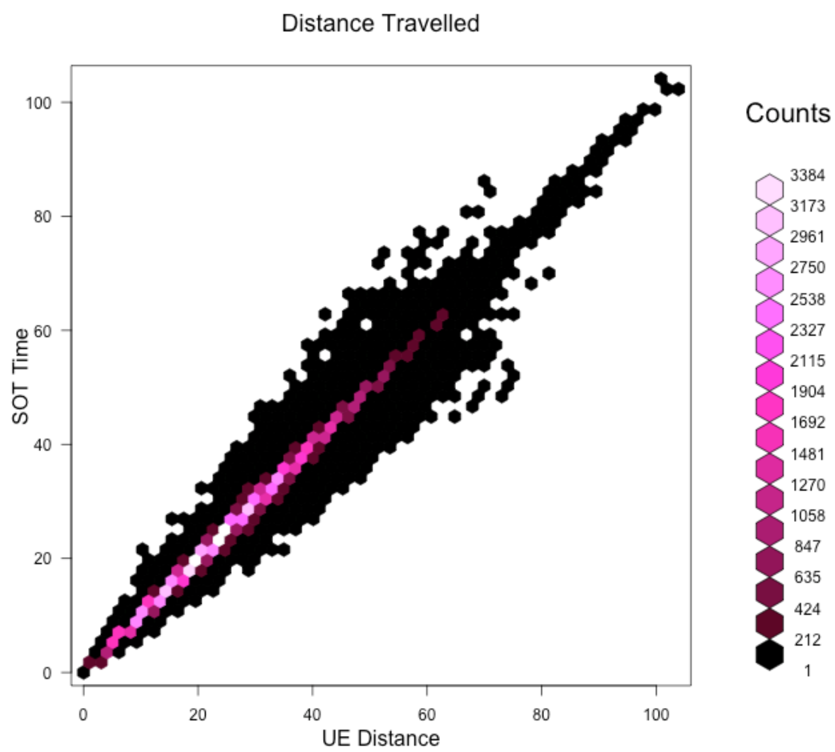
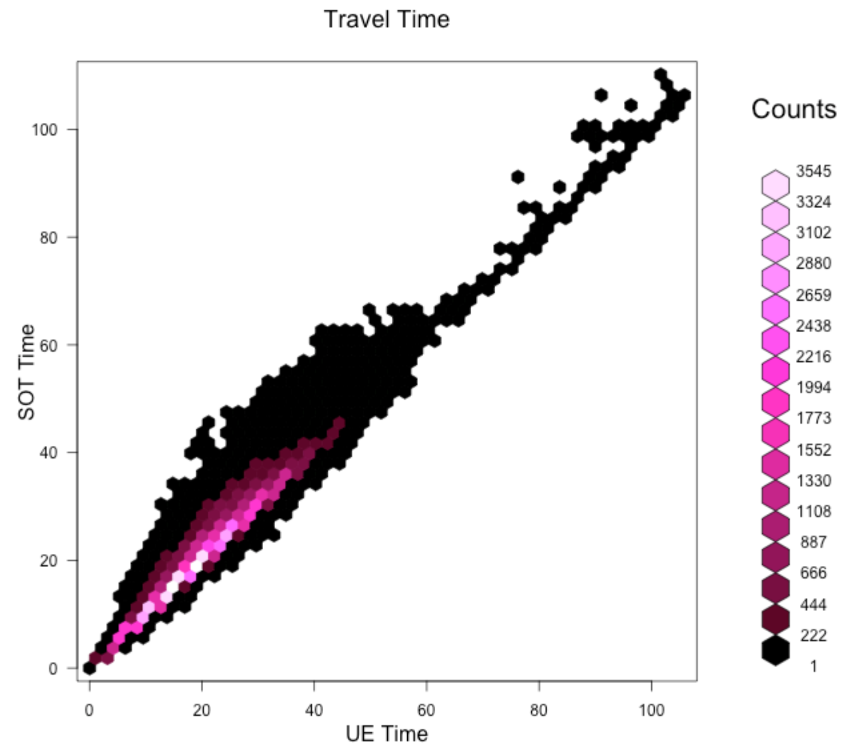
Impact of System Travel Time Optimization





Normalized to User Equilibrium Travel Time

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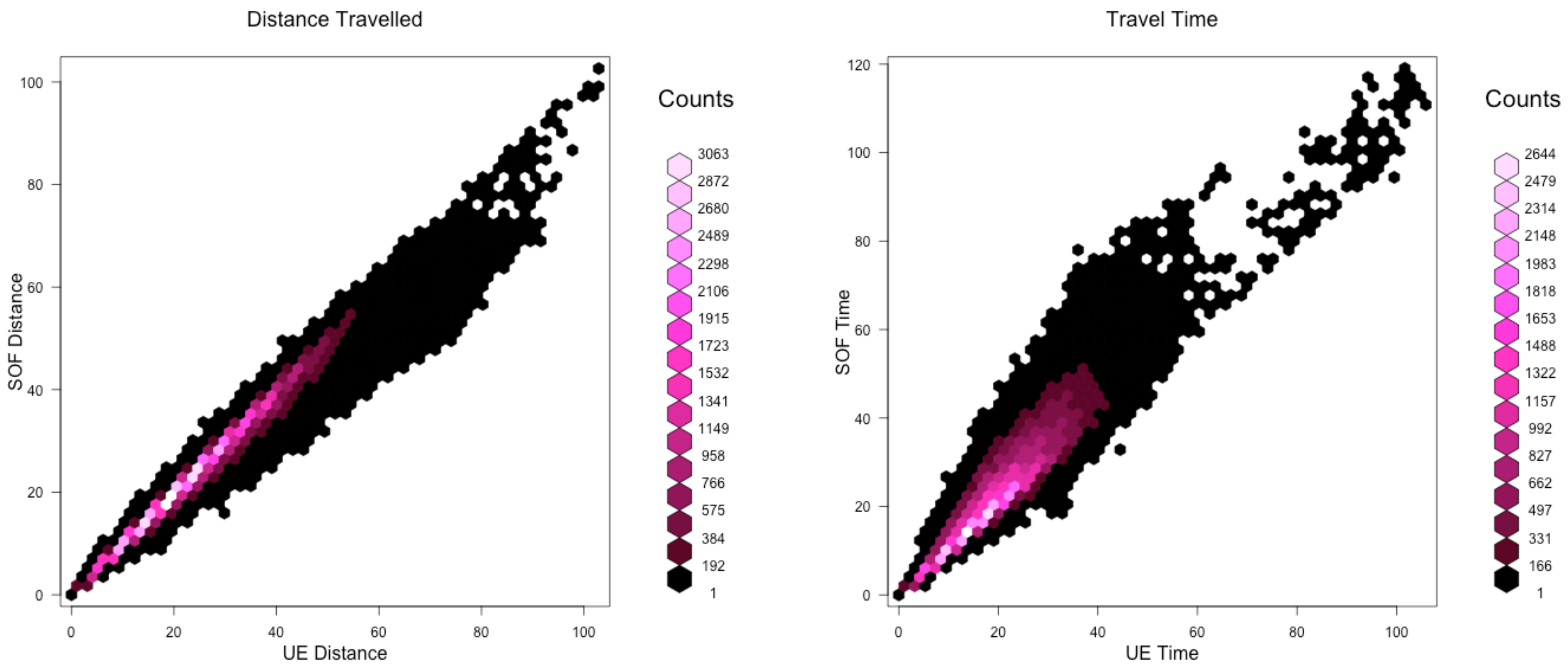
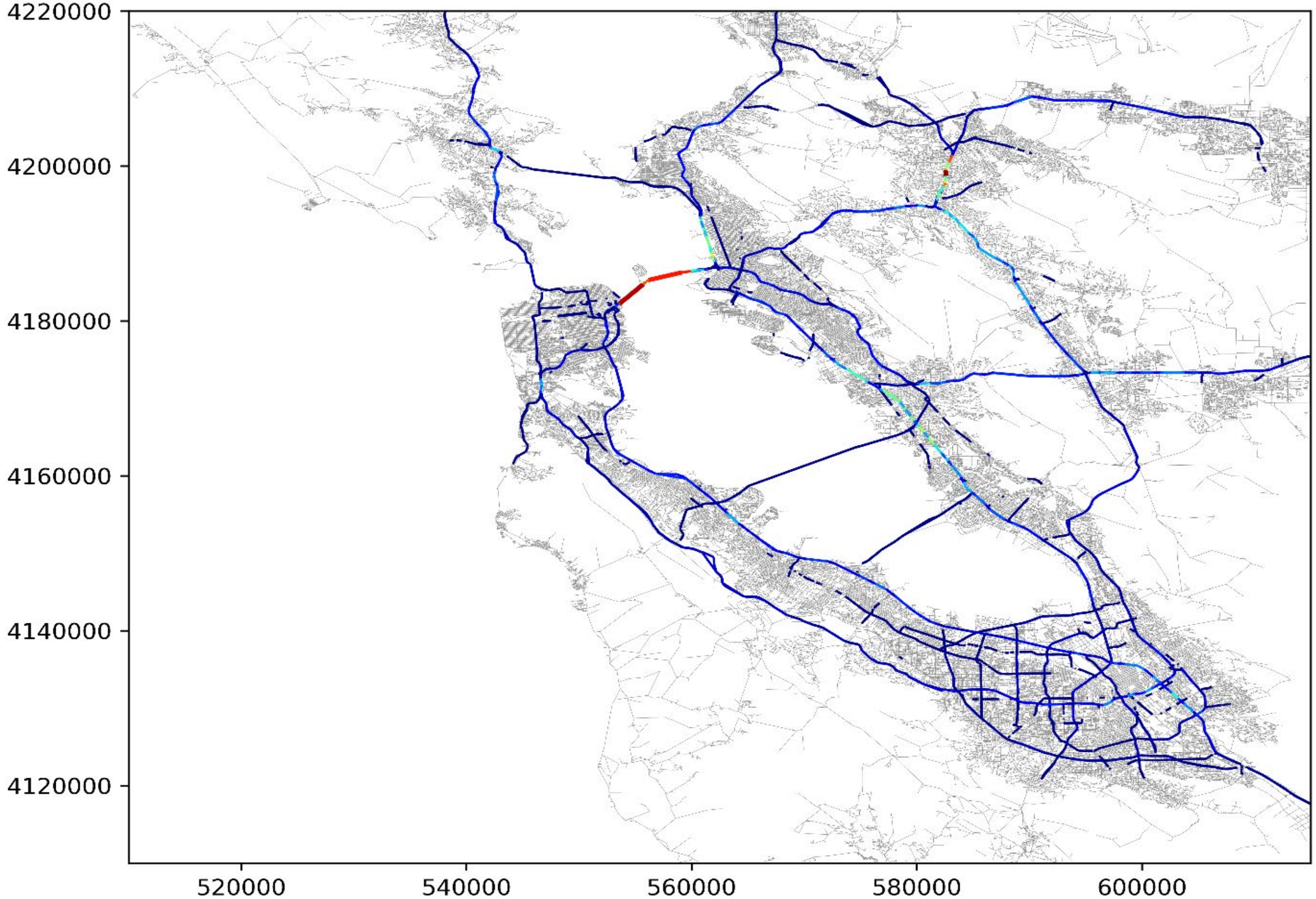
Impact of System Fuel Optimization



Normalized to User Equilibrium Travel Time

Bay Area: System Optimal Travel Time Flow

30 minute compute time



SOT, 22 million OD pairs, top 5000 links

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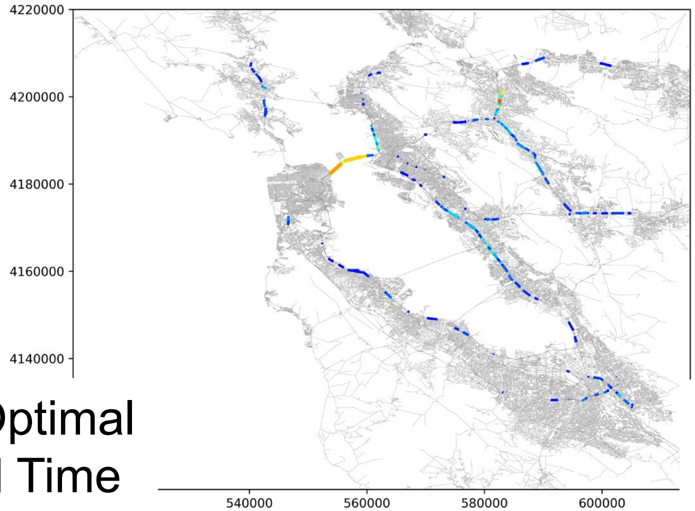
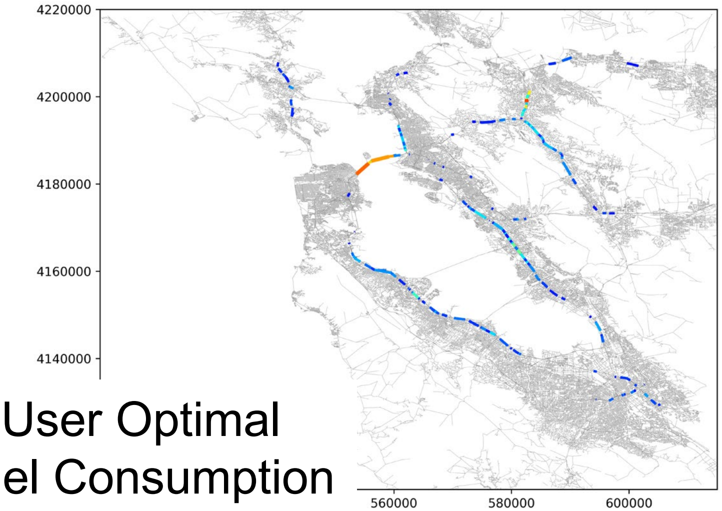
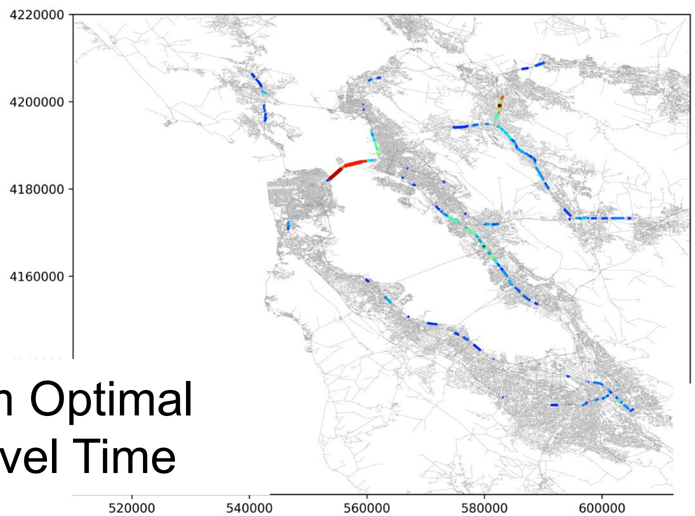
Bay Area (Top 500 Flow Links)



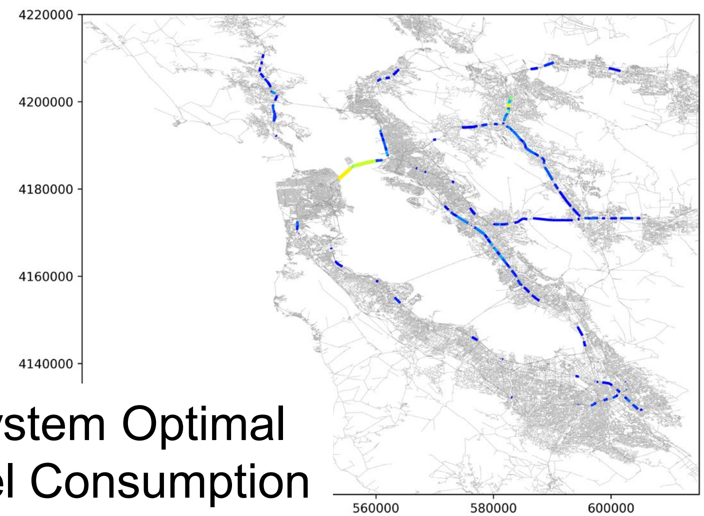
User Optimal
Travel Time



User Optimal
Fuel Consumption



System Optimal
Travel Time



System Optimal
Fuel Consumption

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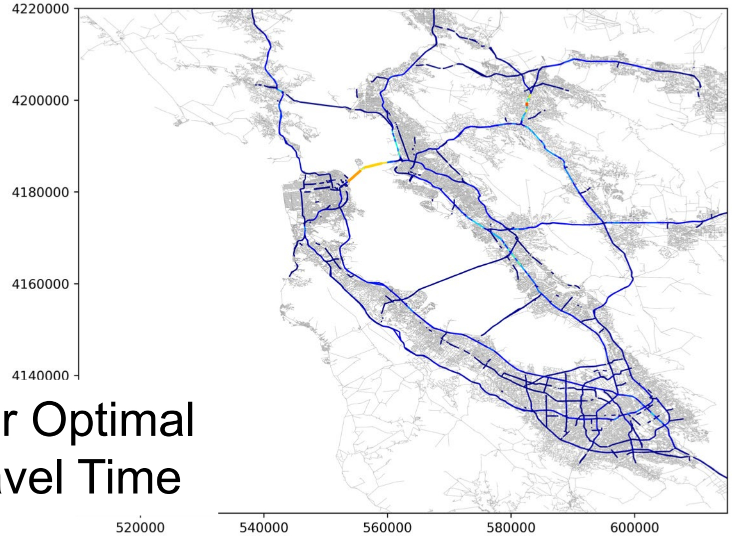
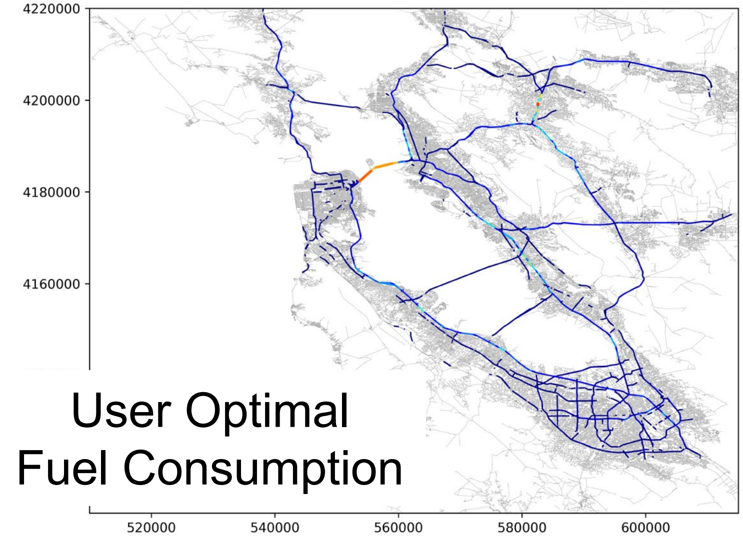
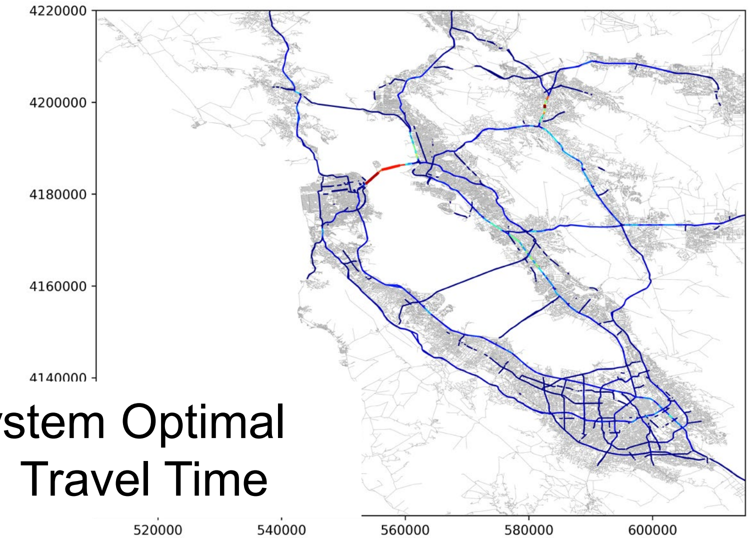
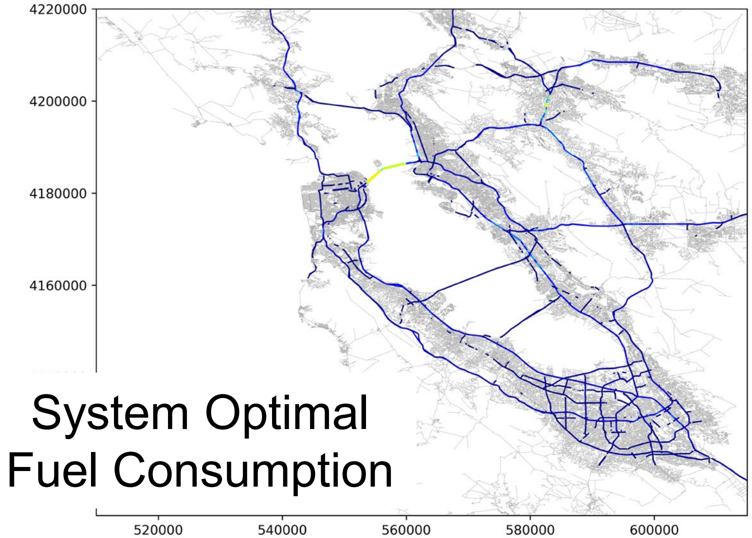
Bay Area (Top 5000 Links)









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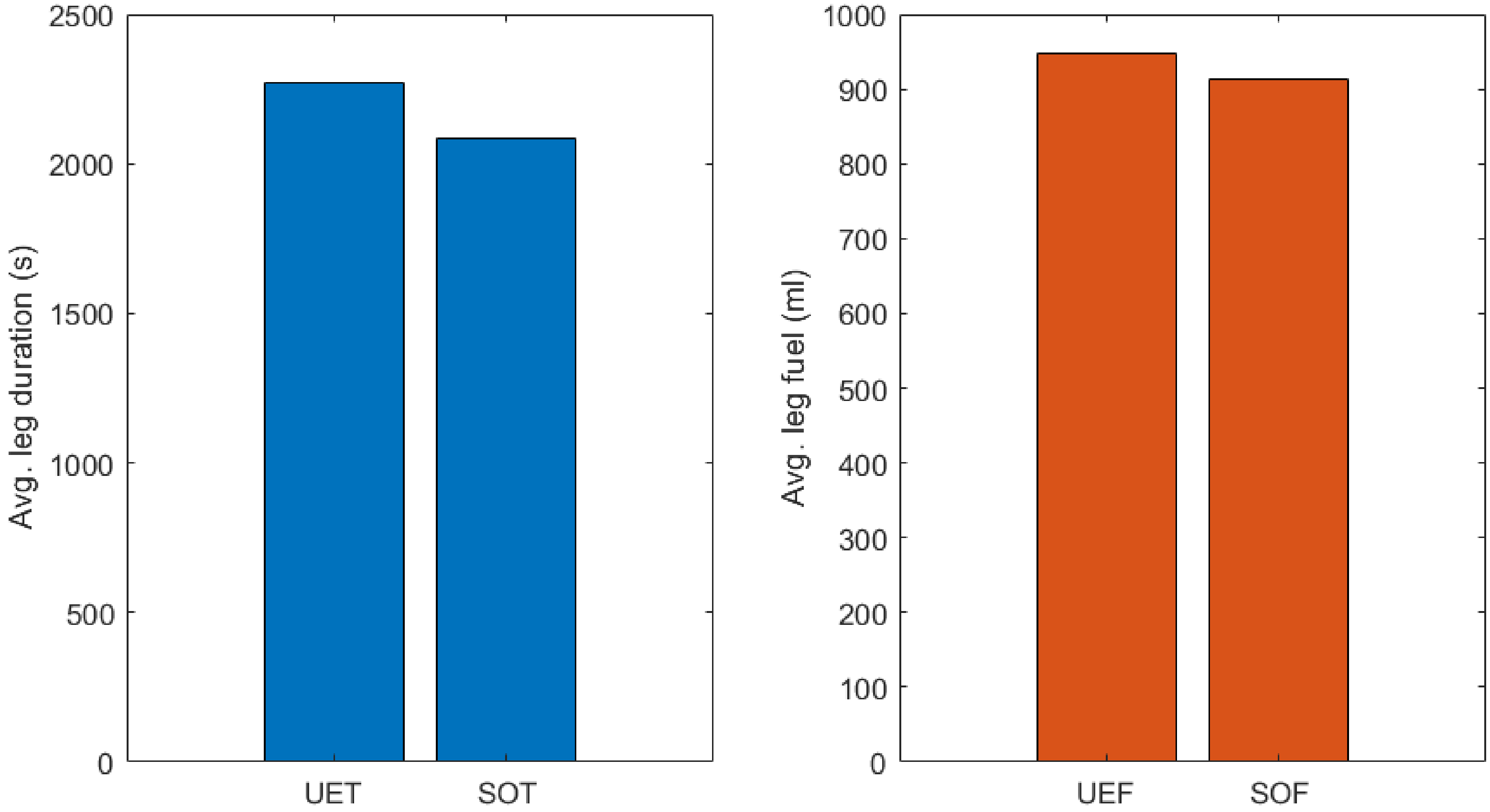
Bay Area Metrics



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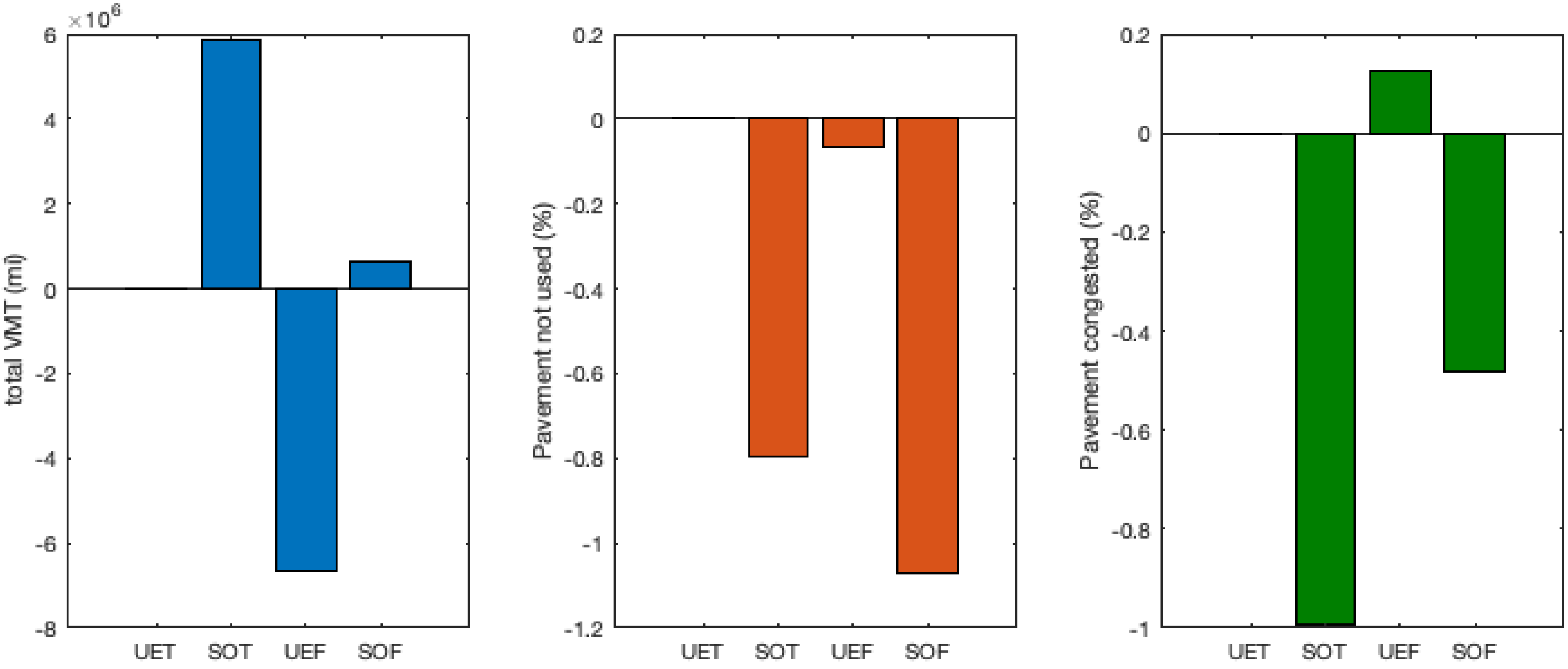
Bay Area Network Utilization



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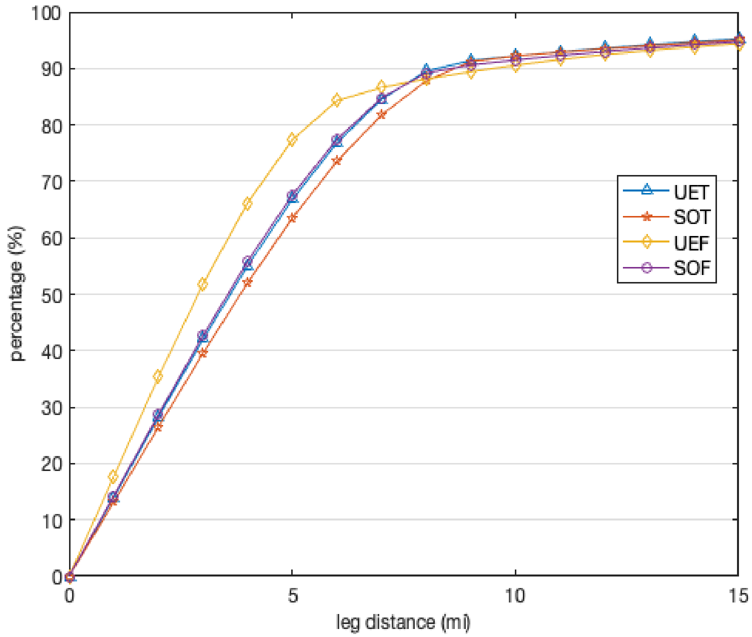
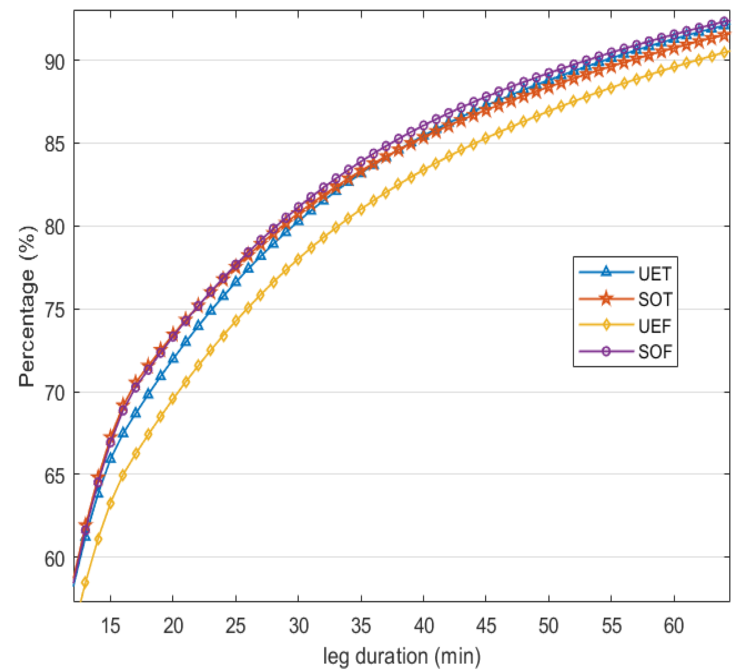
Results for the Bay Area





Collaboration

UC Berkeley | ITS/PATH

Connected Corridors Program

Caltrans

The Connected Corridors program in Los Angeles currently focuses on traffic management in a corridor. We have been requested to expand the scope of management from corridors to regions. When trying to understand overall traffic routing patterns over a region, performing a traffic assignment computation can be time-consuming, perhaps taking days. This is unfortunate because route choice behavior takes place at a large scale and without an understanding of route choice, traffic management strategies are sub optimal at best. **The use of HPC to support tools that run at scale, in real time, meets a need that has existed for quite some time. We hope to use these tools in the next phase of the Connected Corridors program.** We wish to thank the DOE for their foresight in supporting transportation research.

Joe Butler, Program Manager Connected Corridors

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Proposed Future Research

- **Dynamic traffic assignment** with more detailed models to capture the **temporal and spatial** patterns of system dynamics at both the vehicle level and the transportation system level. Specifically, 400K micro analysis zones with 10 minute blocks.
- **Intelligent parallel algorithms** to accelerate the convergence of the DTA algorithms for **metropolitan scale** simulations.
- Build and validate models to combine the **residual demand and new demand** for high-fidelity micro TA.
- Incorporate the DTA models with **sensor data** to inform the intelligent deployment of **Connected and Autonomous Vehicles (CAV)** scenarios.

Any proposed future work is subject to change based on funding levels

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Summary

- Implemented **4 TA optimization cases** on HPC: User-equilibrium time-based (UET), User-equilibrium fuel-based (UEF), System-optimal time-based (SOT) and System-optimal fuel-based (SOF)
- Showed significant **savings of time and fuel** by the optimization-based TA solutions compared to un-optimized scenarios; For the Bay Area case, system-optimal TA (**SOT**) will reduces the average leg duration by **8.47%** compared to the user-equilibrium based approaches (**UET**). The average leg fuel consumption of **SOF** is **3.59%** less than the **UEF**.
- Considerably accelerated computation using HPC platform at LBNL (Cori Supercomputer and GasNet Library) from 5 hours to 30 minutes for the Bay Area network
- Mobiliti Framework allowed for shared network representations for validation of metrics
- **Transferrable models** for metropolitan scale simulation – will be able to evaluate full transportation networks of LA

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